OPTIMAL DISPATCH OF POWER GENERATION SOFTWARE PACKAGE USING MATLAB

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ABSTRACT

In the reality practical power system, power plants are not at the same distance from the centre of load and their fuel costs are different. Also, under normal operating condition the generation capacity is more than the total load demand and losses. Thus there is one main option for scheduling generation that is called optimal dispatch. Optimal dispatch of power generation is to find an effective real and reactive power scheduling to power plants to meet load demand as well as to minimize the operating cost. This cost function may present economic cost, system security and others but in this project, the analysis will limited to the economic dispatch of real power generation. This economic dispatch analysis has been studied by many researchers using different method. However this analysis is very difficult and takes much time to be done by hand calculations. The existence of this optimal dispatch of power generation software package will help the consumer to make this analysis done easier. This friendly software package will be a good medium for researcher to obtain optimal dispatch of power generation without really much effort on hand calculation.

CHAPTER 1

INTRODUCTION

1.1 Introduction

In the practical power system, power plants are not at the same distance from the centre of load and their fuel costs are different. Also, under normal operating condition the generation capacity is more than the total load demand and losses. Thus there is one main option for scheduling generation that is called optimal dispatch. Optimal dispatch of power generation is to find an effective real and reactive power scheduling to power plants to meet load demand as well as minimize the operating cost. This cost function may present economic cost, system security and others but in this project, the analysis will limited to the economic dispatch of real power generation [5].

This economic dispatch analysis has been studied by many researchers using different method.However this analysis is very difficult and takes much time to be done by hand calculations. The existence of this optimal dispatch of power generation software package will help the users to obtain optimal dispatch of power generation analysis done easier without really much effort on hand calculation [5].

1.2 Objective

The objective of this project is:

i. To study and analyze the real and reactive power scheduling of each power plant in such way as to minimize the operating cost of power generation.
ii. To obtain simulation on optimal dispatch of power generation using MATLAB.
iii. Build a user friendly software package using MATLAB GUI to analyze optimal power flow problem.

1.3 Scope of Project

In this project, there are several scopes that the author needs to cover:

i. Study and analyze the best widely used method between Newton-Raphson, Fast Decouple and Gauss Seidel method to obtain the optimal dispatch power generation.
ii. Simulation and analysis all the methods for Optimal Dispatch in MATLAB. This simulation and analysis had categories by two phases; the first one is based on figure of one line diagram of 5-bus and 26-bus power system with generator. Sample of power system diagram from IEEE will be done in second phase.
iii. Simulation using MATLAB GUI and this stage will be classified to two phases. Development of the GUI gone in two phase, the first phase cover on designing the lay out of GUI and second phase will cover MATLAB GUI programming.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Literature reviews are very important as a reference for making this software package as good as possible. The author has studied many journals and article that had been done by previous researcher especially from IEEE.

2.2 Optimal Dispatch of Power Generation

Optimal dispatch is the operation of generation facilities to produce energy at the lowest cost to reliability serve consumer, recognizing any operational limit of generation and transmission facilities [1]. The power balance constraint for power system demand, transmission loss and total generating power as well as the generating power constraints for all units should be satisfied [6]. This optimization can be done by selected objective functions or cost function while maintaining an acceptable system performance in terms of generator capability limits and the output of compensating device. This cost function may present economic costs, system security, safety and others [5]. In this project, analysis will be limited in economic dispatch or optimal dispatch.

2.3 Problem Formulation

2.3.1 Economic Dispatch Problem [5]

Transmission losses are the major factor and affect the optimum dispatch of generation because usually in a large interconnected network, power have to transmit over long distance with low density areas. One common practice for including the effect of transmission losses is to express the total transmission loss as quadratic function of generator power outputs. The simplest quadratic form is

$$PL - \sum_{i=1}^{ng} . \sum_{j=1}^{ng} \mathrm{Pi\ Bij\ Pj} \tag{1}$$

A more general formula containing a linear term and a constant term is Kron's loss formula

$$PL = \sum_{i=1}^{ng} . \sum_{j=1}^{ng} \mathrm{Pi\ Bij\ Pj} + \sum_{i=1}^{ng} \mathrm{B0i\ Pi} + \mathrm{B00} \tag{2}$$

To minimize the overall generating cost Ci, which is the function of plant output

$$Ct = \sum_{i=1}^{ng} \alpha i + \beta i Pi + \gamma i Pi^2 \tag{3}$$

subject to the constraint the generation should equal total demand plus losses

$$\sum_{i=1}^{ng} Pi = PD + PL \tag{4}$$

satisfying the inequality constraints, expressed as follows;

$$P_{i\,(min)} \leq P_i \leq P_{i\,(max)} = 1,\ldots\ldots,n_g \qquad i = 1,\ldots.,n_g \tag{5}$$

Where,

i : Index of dispatchable units

αi, βi, γi : Cost coefficients of units i

Pi : The generated power of unit i

PL : Transmission line losses

B0i, Bij, B00 : Transmission line coefficients

PD : Total load demand

n : Number of all dispatched units

$Pi_{(min)}$: Minimum generation limits of units i

$Pi_{(max)}$: Maximum generation limits of units i

Using the Lagrange multiplier add adding additional terms to include the equality constraints, we obtain

$$\begin{aligned} \mathcal{L} = Ct + \lambda(PD + PL - \sum_{i=1}^{ng} Pi) + \sum_{i=1}^{ng} \mu i(max)\,(Pi - Pi(\mathrm{max})) \\ + \sum_{i=1}^{ng} \mu i(min)\,(-Pi(\mathrm{min})) \end{aligned} \tag{6}$$

The constraints mean

$\mu i(max) = 0$ when $Pi < Pi(max)$

$\mu i(min) = 0$ when $Pi > Pi(min)$

The minimum of unconstrained function is found at the point where the partials of the function to its variables are zero.

$$\frac{\partial \mathcal{L}}{\partial Pi} = 0 \tag{7}$$

$$\frac{\partial \mathcal{L}}{\partial \lambda} = 0 \tag{8}$$

$$\frac{\partial \mathcal{L}}{\partial \mu i\,(\max)} = Pi - Pi(\max) = 0 \tag{9}$$

$$\frac{\partial \mathcal{L}}{\partial \mu i\,(\min)} = Pi - Pi(\min) = 0 \tag{10}$$

Equation (9) and (10) imply that Pi should not be allowed to go beyond its limit, and when Pi is within its limits $\mu i(min) = \mu i(max) = 0$ and Kuhn-Tucker function becomes the same as the Lagrangian one. First condition, given by (7), results in

$$\frac{\partial Ct}{\partial Pi} + \lambda(0 + \frac{\partial PL}{\partial Pi} - 1) = 0$$

Since

$$Ct = C1 + C2 + ... + Cng$$

then

$$\frac{\partial \mathcal{L}}{\partial Pi} = \frac{\partial Ci}{\partial Pi}$$

and the condition for optimum dispatch is

$$\frac{\partial Ci}{\partial Pi} + \lambda \frac{\partial PL}{\partial Pi} - \lambda \qquad i = 1, \ldots\ldots\ldots, n_g \tag{11}$$

The term $\frac{\partial PL}{\partial Pi}$ is knows as the incremental transmission loss. Second condition, given by (8), results in

$$\sum_{i=1}^{ng} Pi = PD + PL \qquad (12)$$

Equation (12) is precisely the equality constraint that was to be imposed.

Equation (11) is rearranged as

$$\left(\frac{1}{1-\frac{\partial PL}{\partial Pi}}\right)\frac{dCi}{dPi} = \lambda \qquad i = 1,\ldots\ldots,n_g \qquad (13)$$

or

$$Li\,\frac{dCi}{dPi} = \lambda \qquad i = 1,\ldots.,n_g \qquad (14)$$

where Li is knows as the *penalty factor* of plant I and is given by

$$Li = \frac{1}{1-\frac{\partial PL}{\partial Pi}} \qquad (15)$$

The effect of transmission loss is to introduce a penalty factor with a value that depends on the location of the plant. Equation (14) shows that the minimum cost is obtained when the incremental cost of each power plant multiplied by its penalty factor is same for all plants.

The incremental production cost is given by

$$\frac{dCi}{dPi} = 2\gamma iPi + \beta i \qquad (16)$$

The incremental production cost (16), and the incremental transmission loss is obtained from the loss formula (2) which yields

$$\frac{\partial PL}{\partial Pi} = 2\sum_{j=1}^{ng} BijPj + B0i \qquad (17)$$

Substituting the expression for the incremental production cost and the incremental transmission loss in (11) results in

$$\beta i + 2\gamma iPi + 2\lambda \sum_{j=1}^{ng} BijPj + B0i\lambda = \lambda$$

or

$$\left(\frac{\gamma i}{\lambda} + Bii\right)Pi + \sum_{\substack{j=1 \\ j\neq i}}^{ng} BijPj + \frac{1}{2}\left(1 - B0i - \frac{\beta i}{\lambda}\right) \qquad (18)$$

Extending (18) to all plants results in matrix form

$$\begin{bmatrix} \frac{\gamma 1}{\lambda} + B11 & B12 & \cdots & B1ng \\ B21 & \frac{\gamma 2}{\lambda} + B22 & \cdots & B2ng \\ \vdots & \vdots & \ddots & \vdots \\ Bng1 & Bng2 & \cdots & \frac{\gamma ng}{\lambda} + Bngng \end{bmatrix} \begin{bmatrix} P1 \\ P2 \\ \vdots \\ Png \end{bmatrix} = \frac{1}{2}\begin{pmatrix} 1 - B01 - \frac{\beta 1}{\lambda} \\ 1 - B02 - \frac{\beta 2}{\lambda} \\ \vdots \\ 1 - B0ng - \frac{\beta ng}{\lambda} \end{pmatrix} \qquad (19)$$

or in short form

$$EP = D \qquad (20)$$

To find the optimal dispatch for estimated value of $\lambda^{(1)}$, the simultaneous linear equation given by (20) is solved.

Then, we continue the iterative process using the gradient method. To do this, from (18), Pi at the k^{th} iteration is expressed as

$$Pi^{(k)} = \frac{(1 - B0i) - \beta i - 2\lambda^{(k)} \sum_{j \neq i} BijPj^{(k)}}{2(\gamma i + \lambda^{(k)} Bii} \tag{21}$$

Substituting for Pi from (21) in (12) results in

$$\sum_{i=1}^{ng} . \frac{\lambda^{(k)}(1 - B0i) - \beta i - 2\lambda^{(k)} \sum_{j \neq i} BijPj^{(k)}}{2(\gamma i + \lambda^{(k)} Bii} = PD + PL^{(k)} \tag{22}$$

or

$$f(\lambda)^{(k)} = PD + PL^{(k)} \tag{23}$$

Expending the left-hand side of the above equation in Taylor's series about an operating point $\lambda^{(k)}$, and neglecting the higher-order terms results in

$$f(\lambda)^{(k)} + \left(\frac{df\lambda}{d\lambda}\right).^{(k)} \Delta\lambda^{(k)} = PD + PL^{(k)} \tag{24}$$

or

$$\Delta\lambda^{(k)} = \frac{\Delta P^{(k)}}{\left(\frac{df(\lambda)}{d\lambda}\right)^{(k)}} = \frac{\Delta P^{(k)}}{\sum\left(\frac{dPi}{d\lambda}\right)^{(k)}} \tag{25}$$

where

$$\sum_{i=1}^{ng} \left(\frac{\partial Pi}{\partial \lambda}\right)^{(k)} = \sum_{i=1}^{ng} \frac{\gamma i(1 - B0i) + Bii\beta i - 2\gamma \sum_{j \neq i} BijPj^{(k)}}{2(\gamma i + \lambda^{(k)} Bii)^2} \tag{26}$$

therefore,

$$\lambda^{(k+1)} = \lambda^{(k)} + \Delta\lambda^{(k)} \tag{27}$$

where

$$\Delta P^{(k)} = PD + PL^{(k)} - \sum_{i=1}^{ng} Pi^{(k)} \tag{28}$$

The process is continued until $\Delta P^{(k)}$ is less than a specified accuracy.

If an appropriate loss formula expressed by

$$PL = \sum_{i=1}^{ng} BiiPi^2 \tag{30}$$

is used, Bij = 0, B00 = 0, and the solution of the simultaneous equation given by (21) reduces to the following simple expression

$$Pi^{(k)} = \frac{\lambda^{(k)} - \beta i}{2(\gamma i + \lambda^{(k)} Bii)} \tag{31}$$

and (28) reduces to

$$\sum_{i=1}^{ng} \frac{\partial y^{(k)}}{\partial x} = \sum_{i=1}^{ng} \frac{\lambda^{(k)} - \beta i}{2(\gamma i + \lambda^{(k)} Bii)^2} \tag{32}$$

2.4 MATLAB GUI

A graphical user interface (GUI) is a graphical display that contains devices, or components, that enable a user to perform interactive tasks. A good GUI can make programs easier to use by providing them with a friendly appearance and with controls icon like pushbuttons, list boxes, sliders, menus, radio button and so forth (refer to appendix A1). To perform these tasks, the user of the GUI does not have to create a script or type commands at the command line. Often, the user does not have to know the details of the task at hand. The GUI should behave in an understandable and predictable manner, so that a user knows what to expect when he or she performs an action. For example, when a mouse click occurs on a pushbutton, the GUI should initiate the action described on the label of the button [2] [3].

Each component, and the GUI itself, are associated with one or more user-written routines known as callbacks. The execution of each callback is triggered by a particular user action such as a button push, mouse click, selection of a menu item, or the cursor passing over a component. The creator of the GUI will provide these callbacks. MATLAB enables the user to create GUIs programmatically or with GUIDE, an interactive GUI builder. It also provides functions that simplify the creation of standard dialog boxes. The technique had chosen depends on the creator experience, preferences, and the kind of GUI that want to create [2] [3].

GUIDE, the MATLAB graphical user interface development environment, provides a set of tools for creating graphical user interfaces (GUIs). These tools simplify the process of laying out and programming GUIs [2] [3].

2.4.1 A Brief Introduction of GUIDE

GUIDE, the MATLAB graphical user interface development environment, provides a set of tools for creating graphical user interfaces (GUIs). These tools simplify the process of laying out and programming GUIs [1].

- GUIDE is primarily a set of layout tools
- GUIDE also generates an M-file that contains code to handle the initialization and launching of the GUI
  - This M-file also provides a framework for the implementation of the callbacks - the functions that execute when users activate a component in the GUI [1].

2.4.2 Two Basic Tasks in Process of Implementing a GUI

The two basic task in Process of implementing a GUI is first, laying out a GUI where MATLAB implement GUIs as figure windows containing various styles of uicontrol (User Interface) objects. The second task is programming the GUI, where each object must be program to perform the intended action when activated by the user of GUI.

2.5 The Similar Software in Market

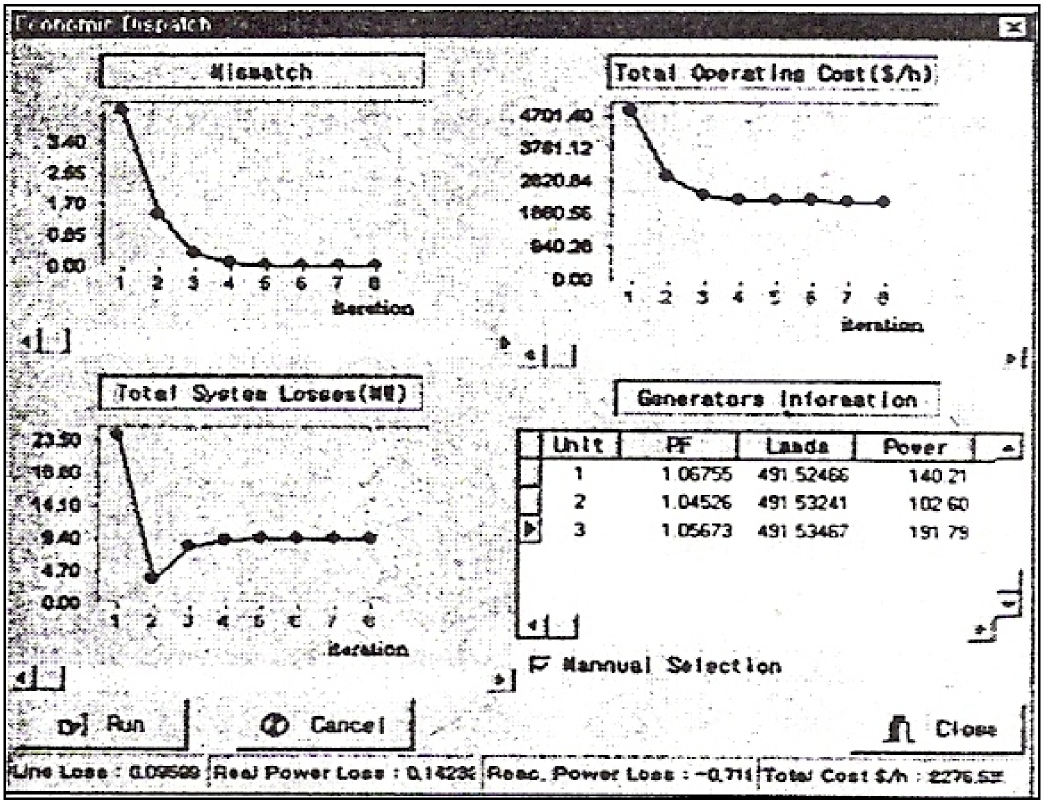

Figure 2.1: Result of Economic Dispatch Analysis.

Figure 2.1 is a software package named Windows-based Interactive and Graphic Package for the Education and Training of Power System Analysis and Operation. This software package is developed by Joong-Rin Shin, Wook-Hwa Lee & Dong-Hae Im from Kon-Kuk University, Seoul, Korea. This software package is developed by GUI and VDBMS using Borland C++.

The application programs in this package include the Power Flow (PF) calculation, the Transient Stability Analysis (TSA), the Fault Analysis (FA), the Economic Dispatch (ED), and the Automatic Load-Frequency Control (ALFC). This application software is designed as independent modules. Each module has a separate graphical and interactive interfacing window. In addition, the user can easily switch from one application module to another.

For the ED problem, this software will show the power mismatch, total operating cost, total system lost and generator information. For the input, the graphic editor has been specially designed to visually edit the one-line diagram of the power system with dialog box on the window [7].

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter presents the methodology of this project. It describes on how the project is organized and the flow of the steps in order to complete this project. The methodology is diverged in two parts, which is the simulation and analysis of Optimal Dispatch in MATLAB and the other is developing the layout and programming for GUI MATLAB.

There are three mains step for software development of this project. Before the project is developing using MATLAB, it is needed to study the method of Optimal Dispatch of Power Generation analysis and how MATLAB GUIDE work. The flowchart in Figure 3.1 illustrated the sequence of steps for this project. The first step is to study about Optimal Dispatch analysis and MATLAB. The second step is to develop the suitable formula of each type of Optimal Dispatch and running the simulation in MATLAB. The last step is developing GUI in MATLAB and programs every GUI component to make sure the software package as friendly as possible to the user.

3.2 Flow Chart of Project

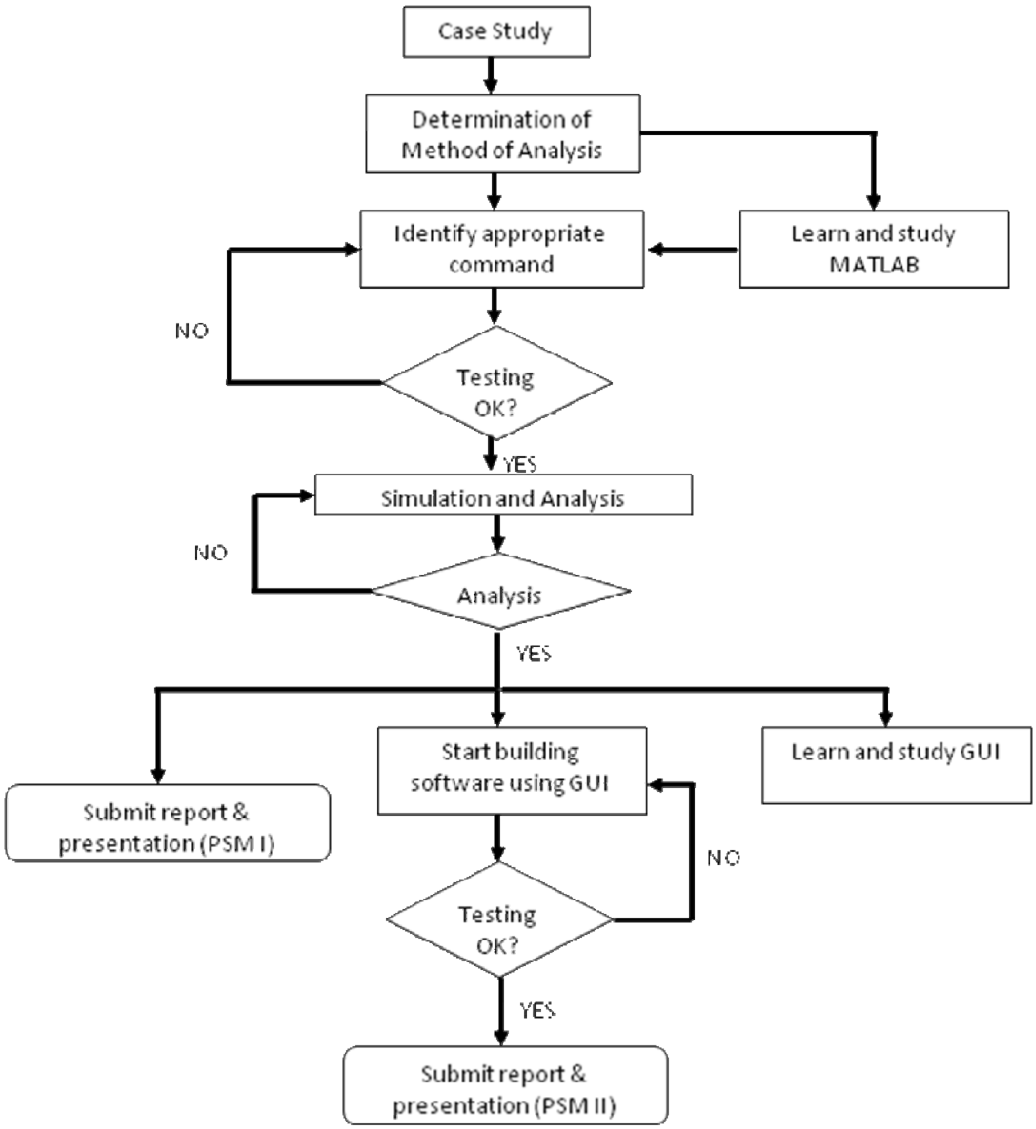

Figure 3.1: Flow Chart of Project

3.3 Problem Simulation

For simulation and analysis using MATLAB, the author has done the simulation for 5 and 26-bus power system network. The simulation had done by using 3 main methods to obtain power flow solution that is Newton-Raphson Method, Gauss-Siedel Method and Fast Decouple Method. The data of the 5 and 26 busbar power system network are described below:

3.3.1 5-Bus Power System Network

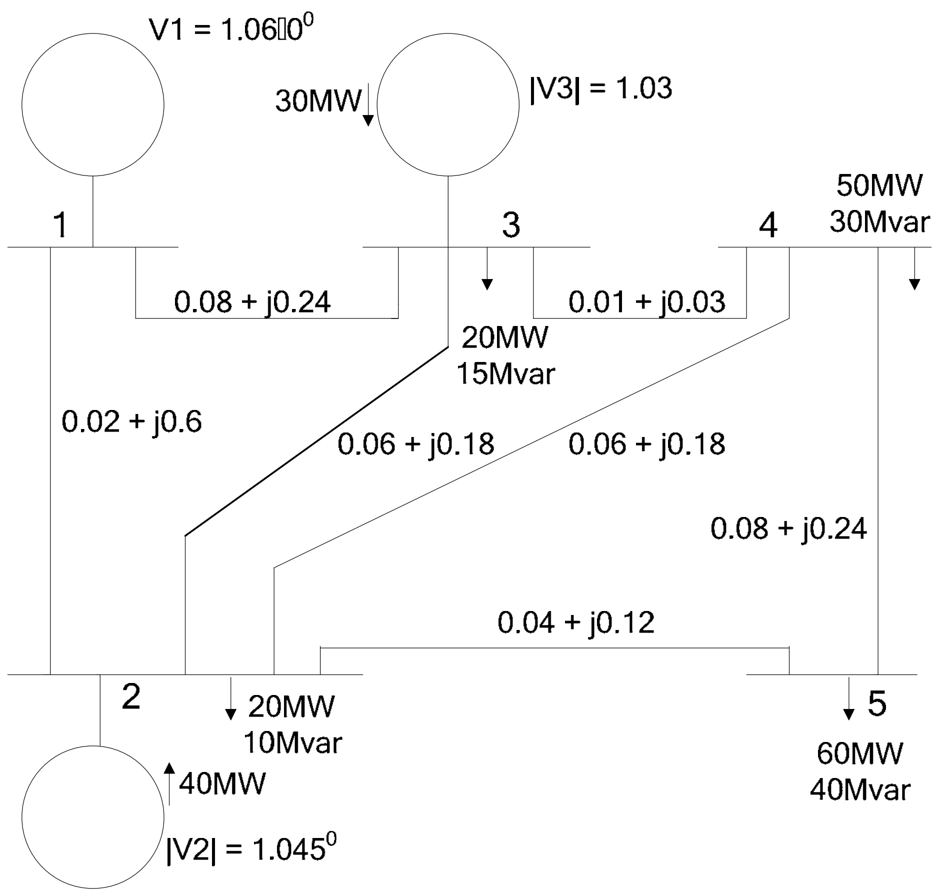

Figure 3.2: One-line diagram of 5-bus power system

Bus 1 taken as the slack bus with its voltage adjusted to $1.06\angle 0^0$

The cost function for P_1, P_2 and P_3 is as follows.

$C_1 = 200 + 7.0P_1 + 0.008P_1^2$

$C_2 = 180 + 6.3P_2 + 0.009P_2^2$

$C_3 = 140 + 6.8P_3 + 0.007P_3^2$

Voltage magnitude, generation schedule and the reactive power limits for the regulated buses are tabulated in Table 3.1.

Table 3.1

GENERATION DATA					
Bus No.	Voltage Magnitude	Generation MW	Generation Mvar	Min. Mvar Capacity	Max. Mvar Capacity
1	1.060	0	0	10	50
2	1.045	40	30	10	50
3	1.030	30	10	10	40
4	1.000	0	0	0	0
5	1.000	0	0	0	0

The generator's real power limits is shown in Table 3.2

Table 3.2

GENERATOR REAL POWER LIMITS		
Gen	Min. MW	Max. MW
1	10	85
2	10	80
3	10	70

The load data is shown in Table 3.3

Table 3.3

LOAD DATA		
Bus No.	Load MW	Mvar
1	0	0
2	20.0	10.0
3	20.0	15.0
4	50.0	30.0
5	60.0	40.0

The line and transformer series resistance, reactance, transformer tap and one-half the total capacitive susceptance in per unit on a 100-MVA base are tabulated below.

Table 3.4

LINE AND TRANSFORMER DATA					
Bus No.	Bus No.	R, pu	X, pu	½ B, pu	Tap Setting pu
1	2	0.02	0.06	0.030	1
1	3	0.08	0.24	0.025	1
2	3	0.06	0.18	0.020	1
2	4	0.06	0.18	0.020	1
2	5	0.04	0.12	0.015	1
3	4	0.01	0.03	0.010	1
4	5	0.08	0.24	0.025	1

3.3.2 26-Bus Power System Network

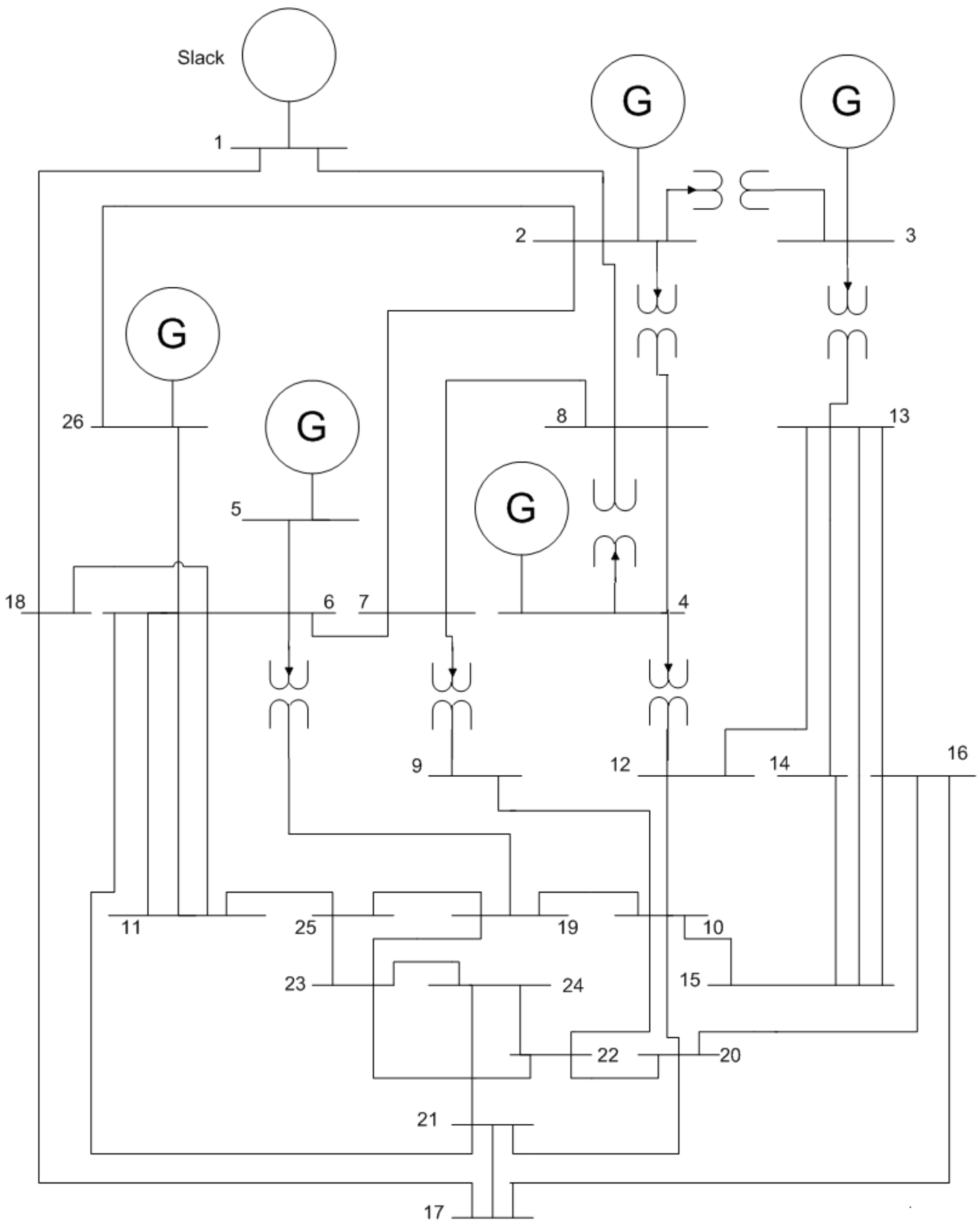

Figure 3.3: One-line diagram of 26-bus power system

Bus 1 taken as the slack bus with its voltage adjusted to $1.06\angle 0^0$

The cost function for P_1, P_2, P_3, P_4, P_5 and P_{26} is as follows.

$C_1 = 240 + 7.0_{P1} + 0.0070_{P1}^2$

$C_2 = 200 + 10.0_{P2} + 0.0095_{P2}^2$

$C_3 = 220 + 8.5_{P3} + 0.0090_{P3}^2$

$C_4 = 200 + 11.0_{P4} + 0.0090_{P4}^2$

$C_5 = 220 + 10.5_{P2} + 0.0080_{P5}^2$

$C_{26} = 190 + 12.0P_{26} + 0.0075P_{26}^2$

Voltage magnitude, generation schedule and the reactive power limits for the regulated buses are tabulated in Table 3.5.

Table 3.5

GENERATION DATA				
Bus No.	Voltage Magnitude	Generation MW	Min. Mvar Capacity	Max. Mvar Capacity
1	1.025			
2	1.020	79.0	40	250
3	1.025	20.0	40	150
4	1.050	100.0	40	80
5	1.045	300.0	40	160
26	1.015	60.0	15	50

Transformer tap settings are giver in the Table 3.6

Table 3.6

TRANSFORMER DATA	
Transformer Designation	Tap Setting Per Unit
2 – 3	0.960
2 – 13	0.960
3 – 13	1.017

4 – 8	1.050
4 – 12	1.050
6 – 19	0.950
7 – 9	0.950

The shunt capacitive data is shown in Table 3.7

Table 3.7

SHUNT CAPACITOR DATA	
Bus No.	Mvar
1	4.0
4	2.0
5	5.0
6	2.0
9	3.0
11	1.5
12	2.0
15	0.5
19	5.0

The generator's real power limits is shown in Table 3.8

Table 3.8

GENERATOR REAL POWER LIMITS		
Gen	Min. MW	Max. MW
1	100	500
2	50	200
3	80	300
4	50	150

5	50	200
5	50	120

The load data is as shown in Table 3.9

Table 3.9

LOAD DATA					
Bus No.	Load		Bus No.	Load	
	MW	Mvar		MW	Mvar
1	51.0	41.0	14	24.0	12.0
2	22.0	15.0	15	70.0	31.0
3	64.0	50.0	16	55.0	27.0
4	25.0	10.0	17	78.0	38.0
5	50.0	30.0	18	153.0	67.0
6	76.0	29.0	19	75.0	15.0
7	0.0	0.0	20	48.0	27.0
8	0.0	0.0	21	46.0	23.0
9	89.0	50.0	22	45.0	22.0
10	0.0	0.0	23	25.0	12.0
11	25.0	15.0	24	54.0	27.0
12	89.0	48.0	25	28.0	13.0
13	31.0	15.0	26	40.0	20.0

The line and transformer series resistance, reactance, transformer tap and one-half the total capacitive susceptance in per unit on a 100-MVA base are tabulated in Table 3.10

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Table 3.10

LINE AND TRANSFORMER DATA									
Bus No.	Bus No.	R, pu	X, Pu	½ B, pu	Bus No.	Bus No.	R, pu	X, pu	½ B, pu
1	2	0.0005	0.0048	0.0300	10	22	0.0069	0.0298	0.0005
1	18	0.0013	0.0110	0.0600	11	25	0.0960	0.2700	0.0010
2	3	0.0014	0.0513	0.0500	11	26	0.0165	0.0970	0.0004
2	7	0.0103	0.0586	0.0180	12	14	0.0327	0.0802	0.0000
2	8	0.0074	0.0321	0.0390	12	15	0.0180	0.0598	0.0000
2	13	0.0035	0.0967	0.0250	13	14	0.0046	0.0271	0.0001
2	26	0.0323	0.1967	0.0000	13	15	0.0116	0.0610	0.0000
3	13	0.0007	0.0054	0.0005	13	16	0.0179	0.0888	0.0001
4	8	0.0008	0.0240	0.0001	14	15	0.0069	0.0382	0.0000
4	12	0.0016	0.0207	0.0150	15	16	0.0209	0.0512	0.0000
5	6	0.0069	0.0300	0.0990	16	17	0.0990	0.0600	0.0000
6	7	0.0053	0.0306	0.0010	16	20	0.0239	0.0585	0.0000
6	11	0.0097	0.0570	0.0001	17	18	0.0032	0.0600	0.0038
6	18	0.0037	0.0222	0.0012	17	21	0.2290	0.4450	0.0000
6	19	0.0035	0.0660	0.0450	19	23	0.0300	0.1310	0.0000
6	21	0.0050	0.0900	0.0226	19	24	0.0300	0.1250	0.0002
7	8	0.0012	0.0069	0.0001	19	25	0.1190	0.2249	0.0004
7	9	0.0009	0.0429	0.0250	20	21	0.0657	0.1570	0.0000
8	12	0.0020	0.0180	0.0200	20	22	0.0150	0.0366	0.0000
9	10	0.0010	0.0493	0.0010	21	24	0.0476	0.1510	0.0000
10	12	0.0024	0.0132	0.0100	22	23	0.0290	0.0990	0.0000
10	19	0.0547	0.2360	0.0000	22	24	0.0310	0.0880	0.0000
10	20	0.0066	0.0160	0.0010	23	25	0.0987	0.1168	0.0000